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Sampath et al.

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(54) **INTERFERENCE REDUCTION USING VARIABLE DIGITAL-TO-ANALOG CONVERTER (DAC) SAMPLING RATES**

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(51) **Int. Cl.**
H04B 1/38 (2006.01)

(52) **U.S. Cl.** **375/219**; 375/222; 375/275; 375/333; 375/346; 341/144; 341/174; 341/176; 341/180; 341/181

(58) **Field of Classification Search** 341/144, 341/174, 176, 180, 181; 375/219, 222, 275, 375/333, 346

See application file for complete search history.

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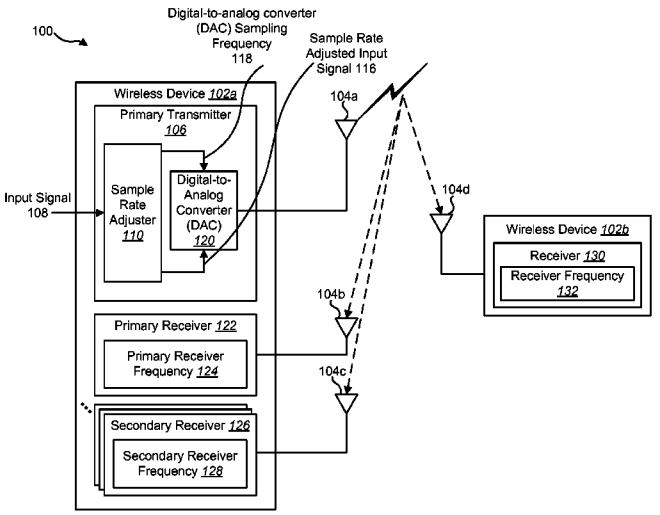
(57) **ABSTRACT**

A method for interference reduction is described. A sampling frequency is selected for a digital-to-analog converter (DAC) so that images within a DAC output signal do not interfere with one or more receivers. A sample rate is adjusted of an input signal that is provided to the DAC to match the sampling frequency for the DAC.

33 Claims, 11 Drawing Sheets



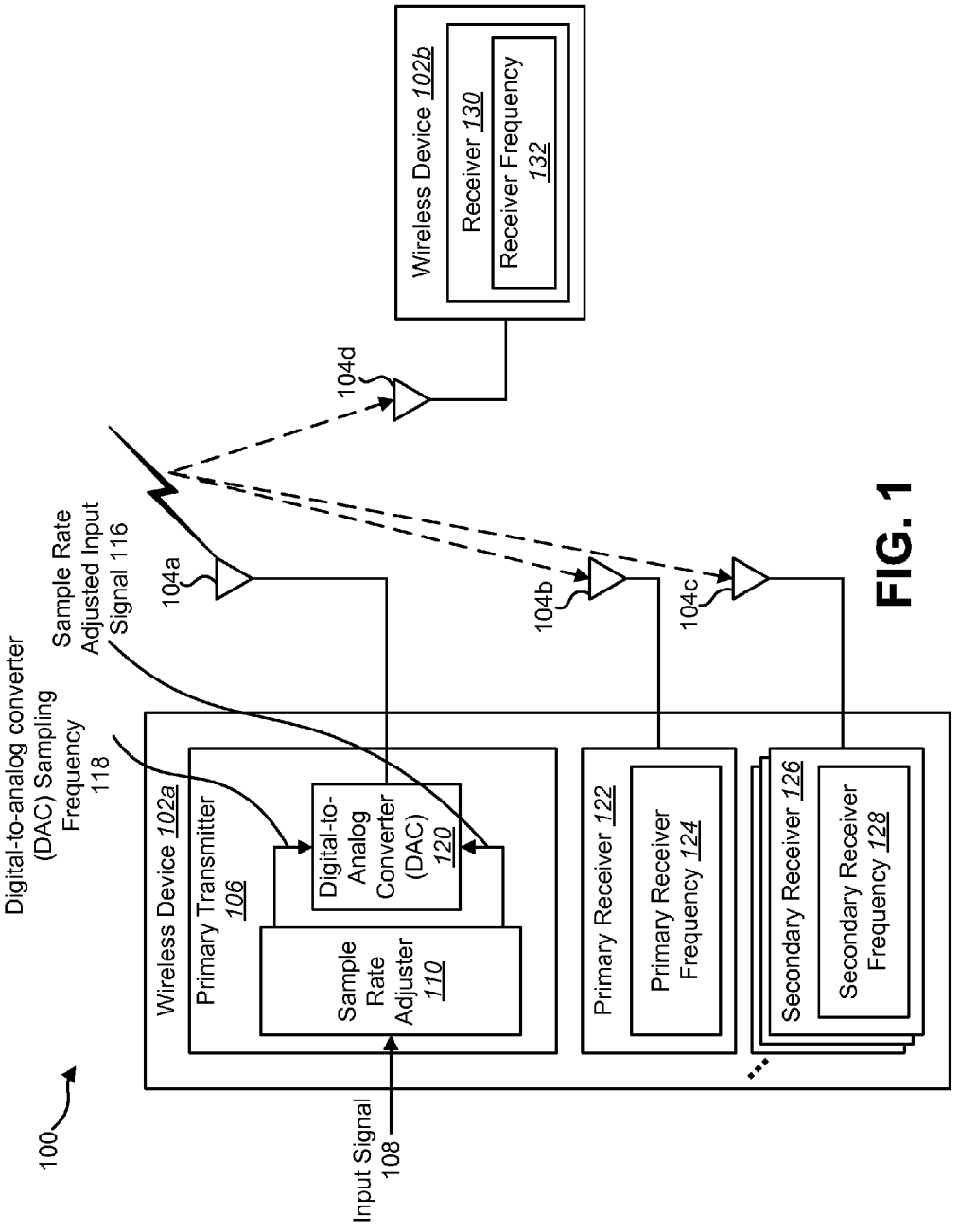

100
Input Signal 108
Wireless Device 102a
Primary Transmitter 106
Sample Rate Adjuster 110
Digital-to-Analog Converter (DAC) 120
Primary Receiver 122
Primary Receiver Frequency 124
Secondary Receiver 126
Secondary Receiver Frequency 128
Digital-to-analog converter (DAC) Sampling Frequency 118
Sample Rate Adjusted Input Signal 116
104a
104b
104c
104d
Wireless Device 102b
Receiver 130
Receiver Frequency 132

FIG. 1

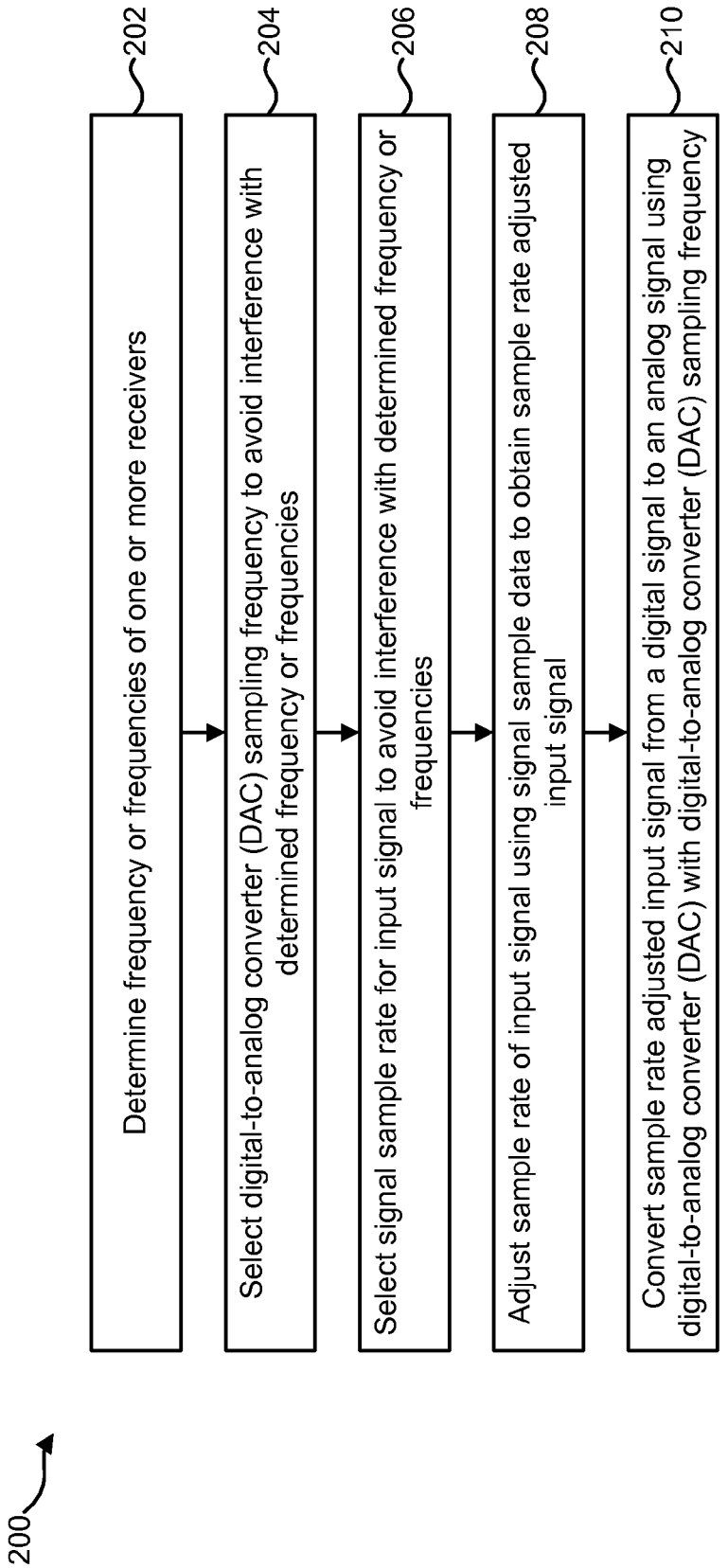

200
202
Determine frequency or frequencies of one or more receivers
204
Select digital-to-analog converter (DAC) sampling frequency to avoid interference with determined frequency or frequencies
206
Select signal sample rate for input signal to avoid interference with determined frequency or frequencies
208
Adjust sample rate of input signal using signal sample data to obtain sample rate adjusted input signal
210
Convert sample rate adjusted input signal from a digital signal to an analog signal using digital-to-analog converter (DAC) with digital-to-analog converter (DAC) sampling frequency

FIG. 2

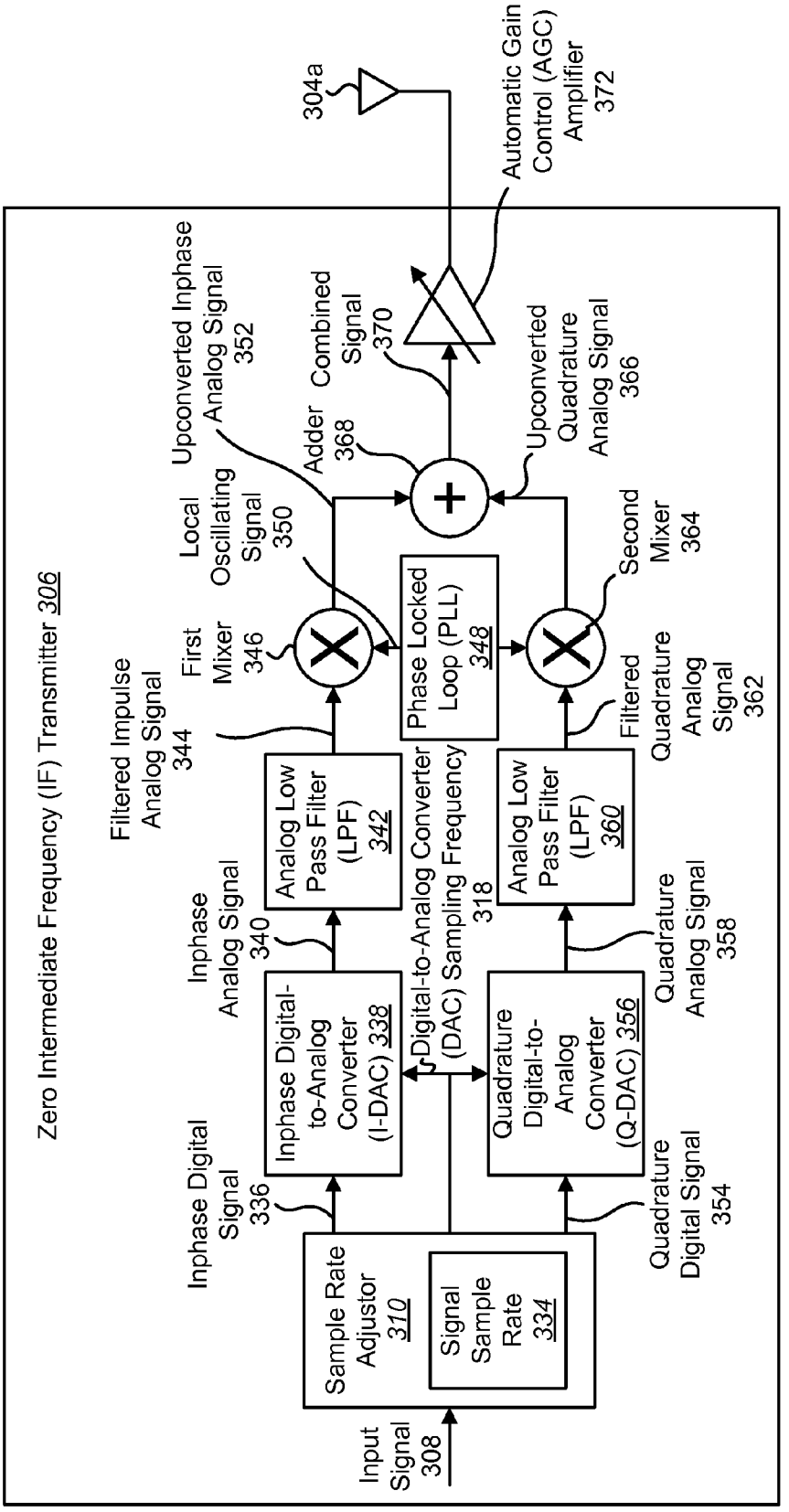

Zero Intermediate Frequency (IF) Transmitter 306
Input Signal 308
Sample Rate Adjustor 310
Signal Sample Rate 334
Inphase Digital Signal 336
Quadrature Digital Signal 354
Inphase Digital-to-Analog Converter (I-DAC) 338
Quadrature Digital-to-Analog Converter (Q-DAC) 356
Digital-to-Analog Converter (DAC) Sampling Frequency 318
Inphase Analog Signal 340
Quadrature Analog Signal 358
Analog Low Pass Filter (LPF) 342
Analog Low Pass Filter (LPF) 360
Filtered Impulse Analog Signal 344
Filtered Quadrature Analog Signal 362
First Mixer 346
Second Mixer 364
Phase Locked Loop (PLL) 348
Local Oscillating Signal 350
Upconverted Inphase Analog Signal 352
Upconverted Quadrature Analog Signal 366
Adder 368
Combined Signal 370
Automatic Gain Control (AGC) Amplifier 372
304a

FIG. 3

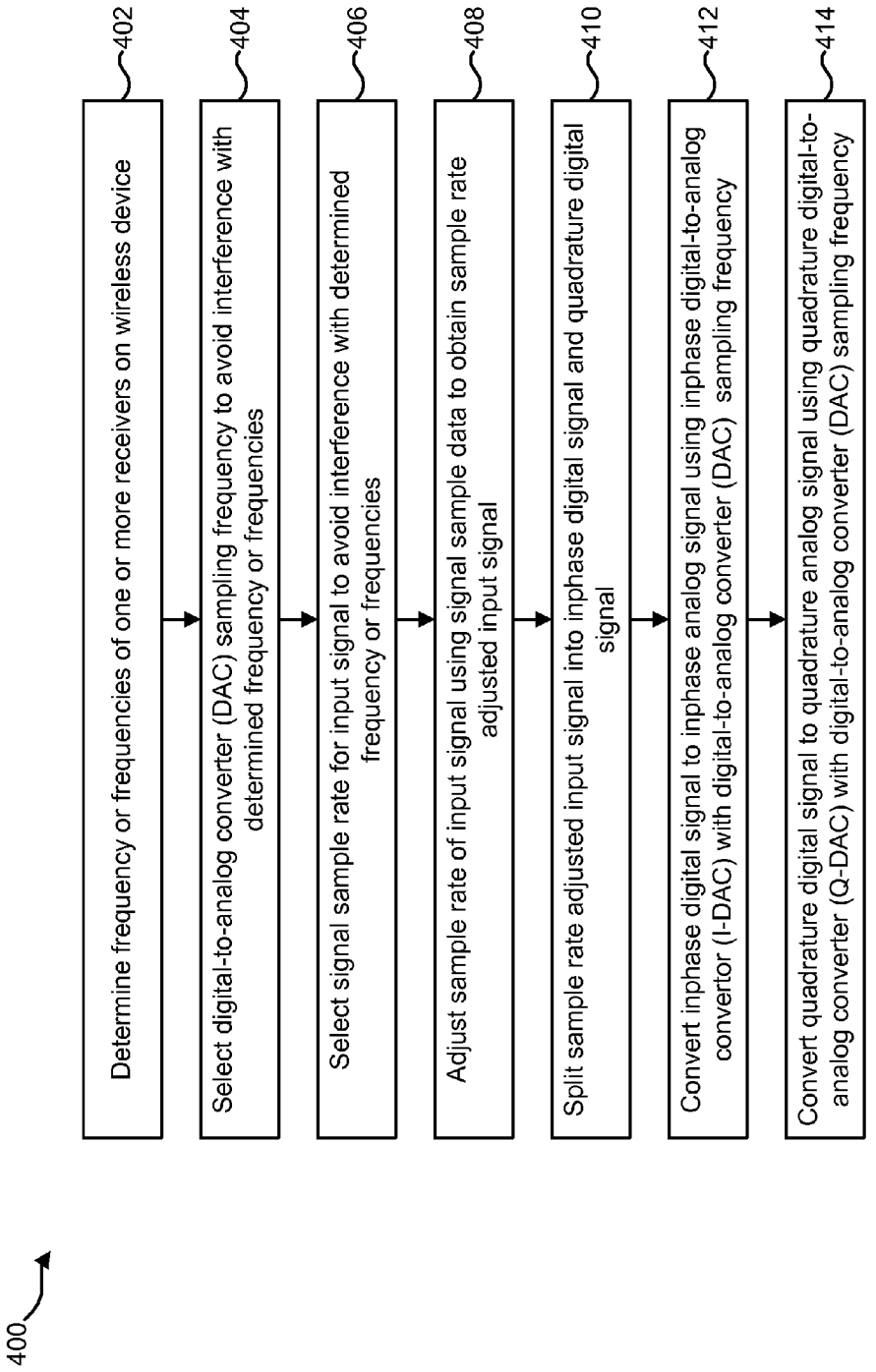

400
402
Determine frequency or frequencies of one or more receivers on wireless device
404
Select digital-to-analog converter (DAC) sampling frequency to avoid interference with determined frequency or frequencies
406
Select signal sample rate for input signal to avoid interference with determined frequency or frequencies
408
Adjust sample rate of input signal using signal sample data to obtain sample rate adjusted input signal
410
Split sample rate adjusted input signal into inphase digital signal and quadrature digital signal
412
Convert inphase digital signal to inphase analog signal using inphase digital-to-analog convertor (I-DAC) with digital-to-analog converter (DAC) sampling frequency
414
Convert quadrature digital signal to quadrature analog signal using quadrature digital-to-analog converter (Q-DAC) with digital-to-analog converter (DAC) sampling frequency

FIG. 4

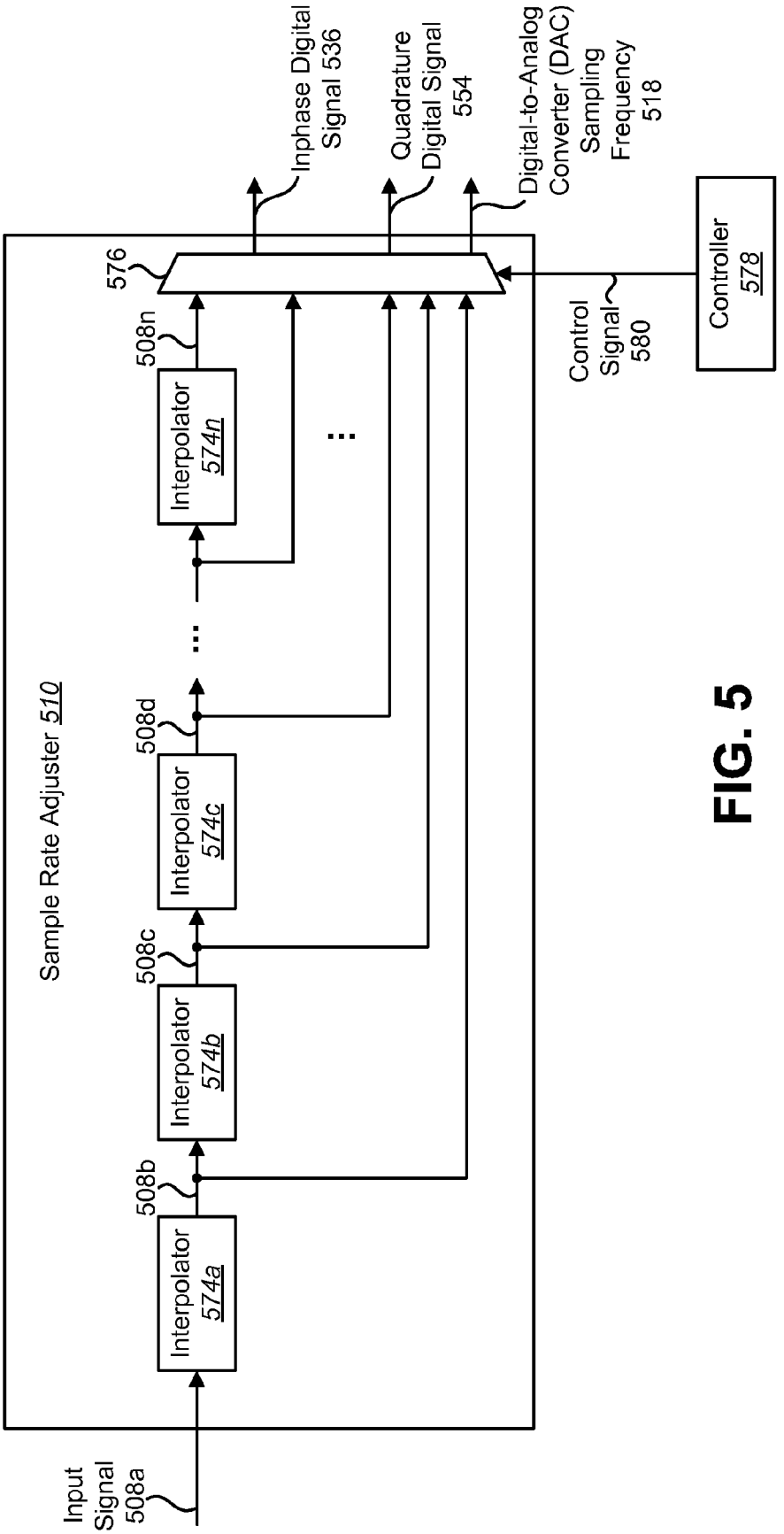

Input Signal 508a
Sample Rate Adjuster 510
Interpolator 574a
Interpolator 574b
Interpolator 574c
Interpolator 574n
508b
508c
508d
508n
576
Inphase Digital Signal 536
Quadrature Digital Signal 554
Digital-to-Analog Converter (DAC) Sampling Frequency 518
Control Signal 580
Controller 578

FIG. 5

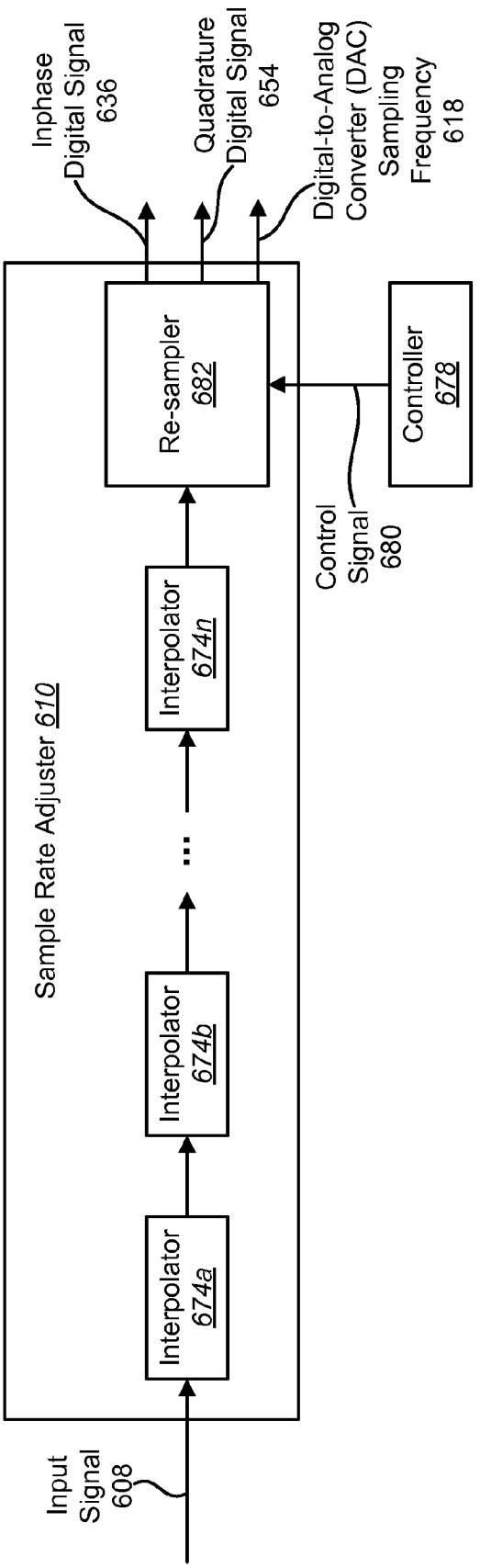

Inphase Digital Signal 636
Quadrature Digital Signal 654
Digital-to-Analog Converter (DAC) Sampling Frequency 618
Re-sampler 682
Controller 678
Control Signal 680
Interpolator 674n
Interpolator 674b
Interpolator 674a
Sample Rate Adjuster 610
Input Signal 608

FIG. 6

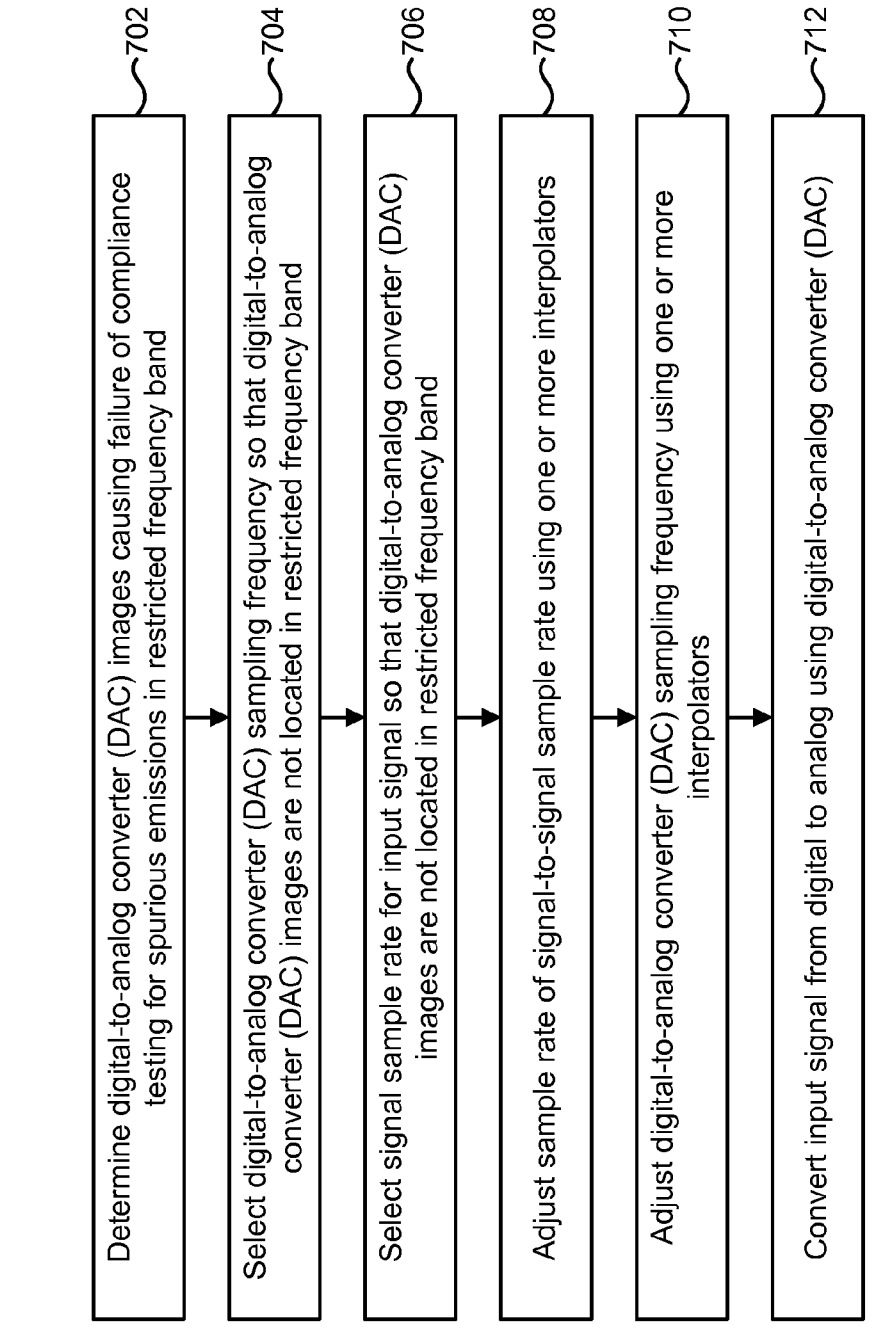

700
702
Determine digital-to-analog converter (DAC) images causing failure of compliance testing for spurious emissions in restricted frequency band
704
Select digital-to-analog converter (DAC) sampling frequency so that digital-to-analog converter (DAC) images are not located in restricted frequency band
706
Select signal sample rate for input signal so that digital-to-analog converter (DAC) images are not located in restricted frequency band
708
Adjust sample rate of signal-to-signal sample rate using one or more interpolators
710
Adjust digital-to-analog converter (DAC) sampling frequency using one or more interpolators
712
Convert input signal from digital to analog using digital-to-analog converter (DAC)

FIG. 7

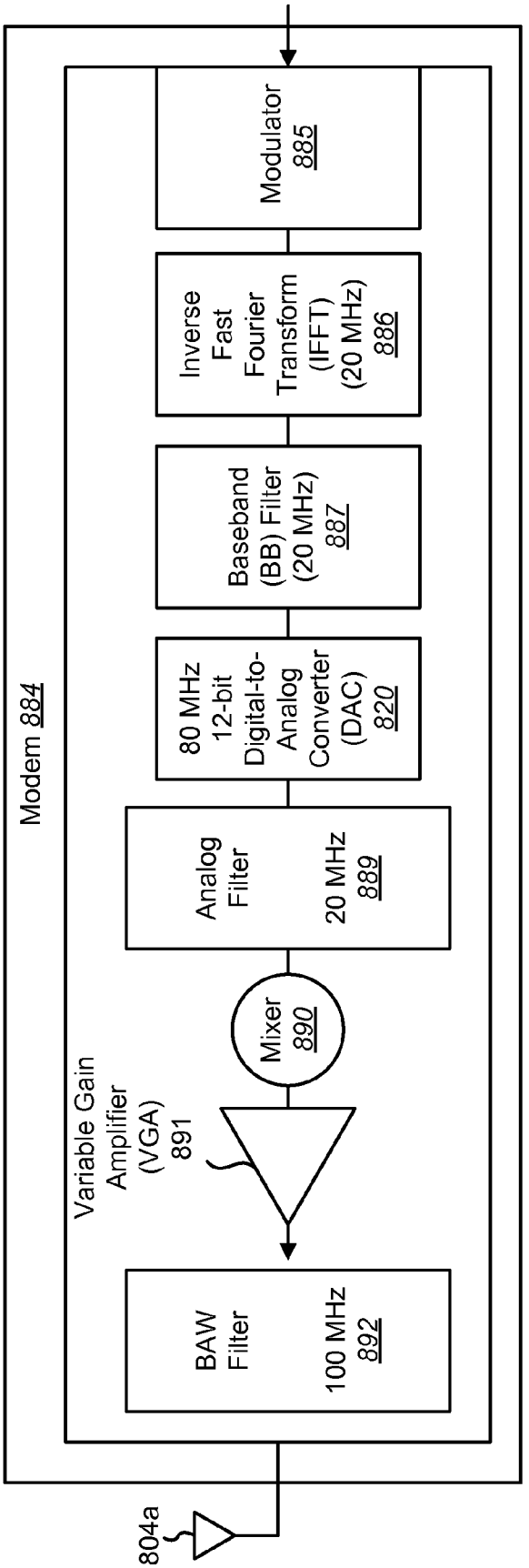

Modem 884
Modulator 885
Inverse Fast Fourier Transform (IFFT) (20 MHz) 886
Baseband (BB) Filter (20 MHz) 887
80 MHz 12-bit Digital-to-Analog Converter (DAC) 820
Analog Filter 20 MHz 889
Mixer 890
Variable Gain Amplifier (VGA) 891
BAW Filter 100 MHz 892
804a

FIG. 8

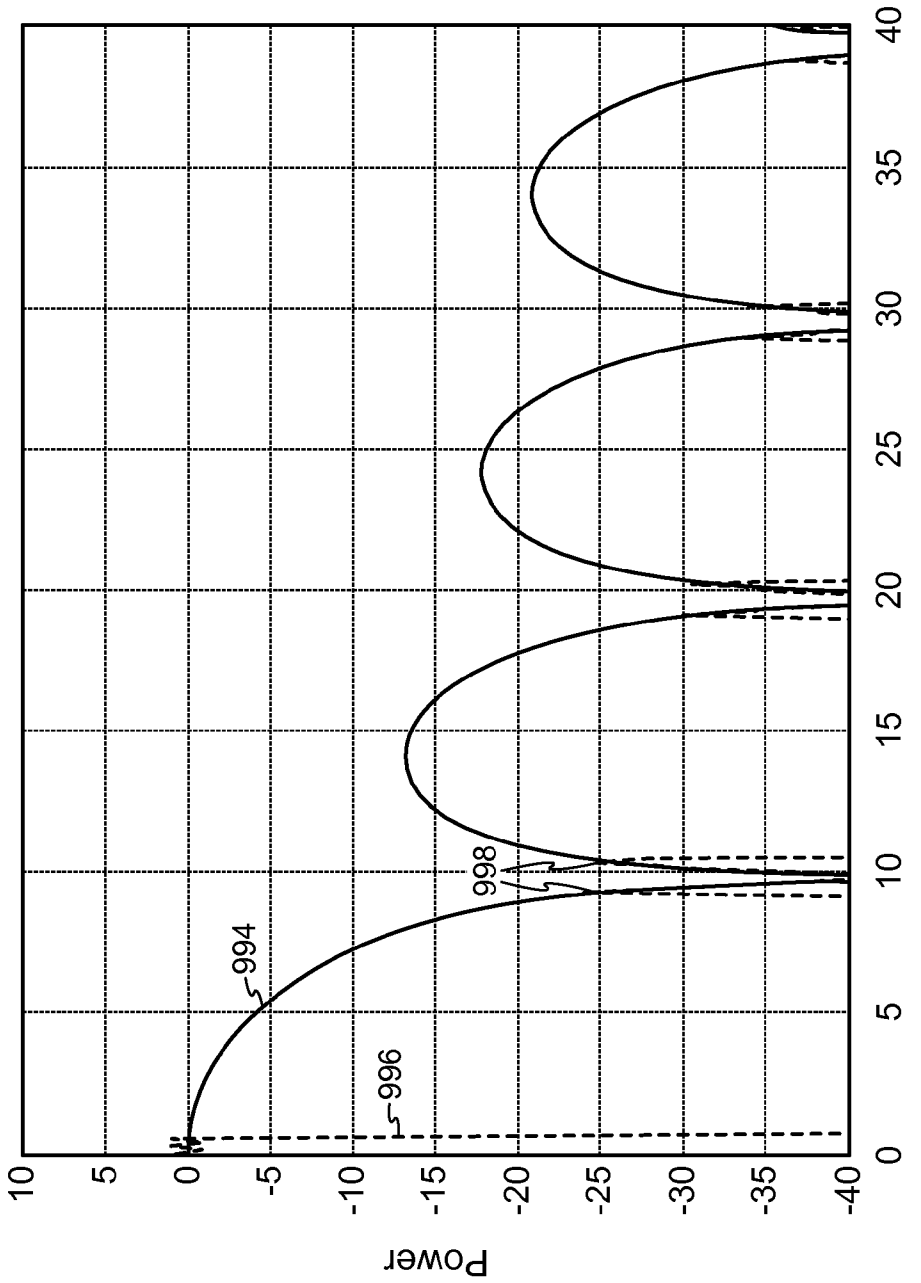

Power
Frequency
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
0
5
10
15
20
25
30
35
40
994
996
998

FIG. 9

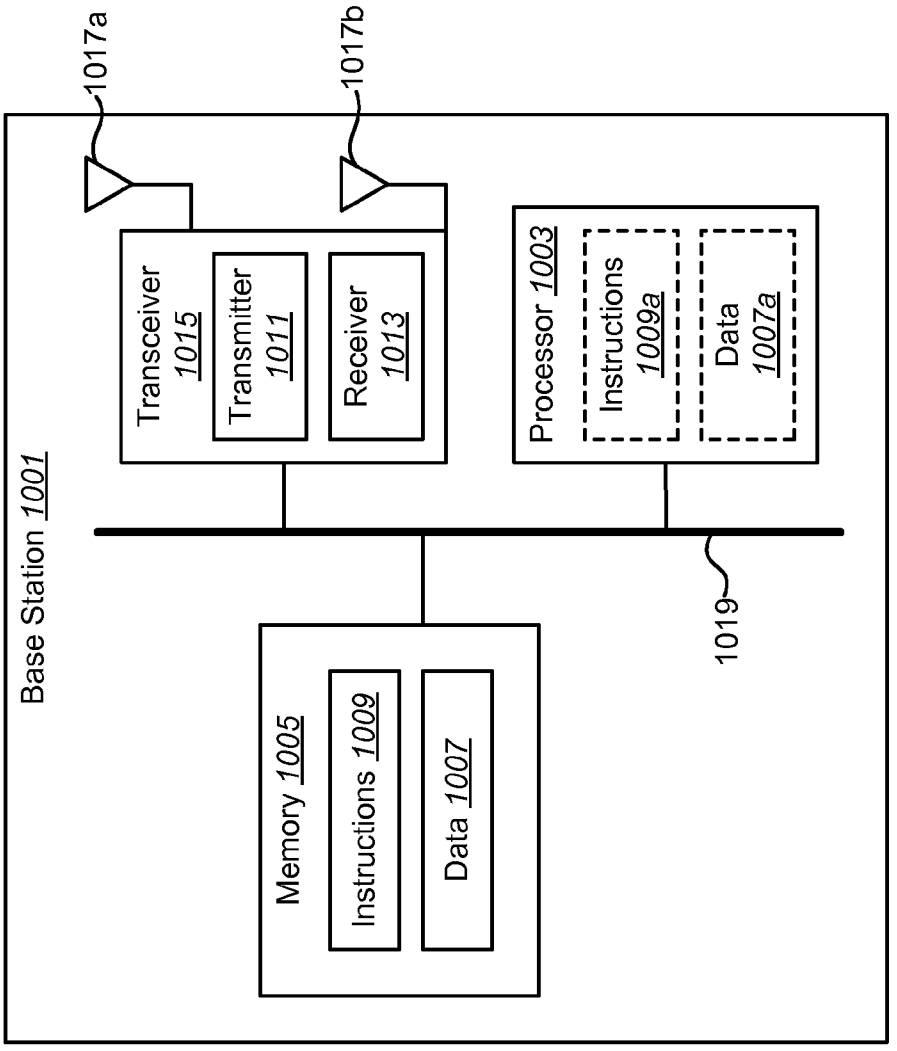

Base Station 1001
1017a
1017b
Transceiver 1015
Transmitter 1011
Receiver 1013
Processor 1003
Instructions 1009a
Data 1007a
1019
Memory 1005
Instructions 1009
Data 1007

FIG. 10

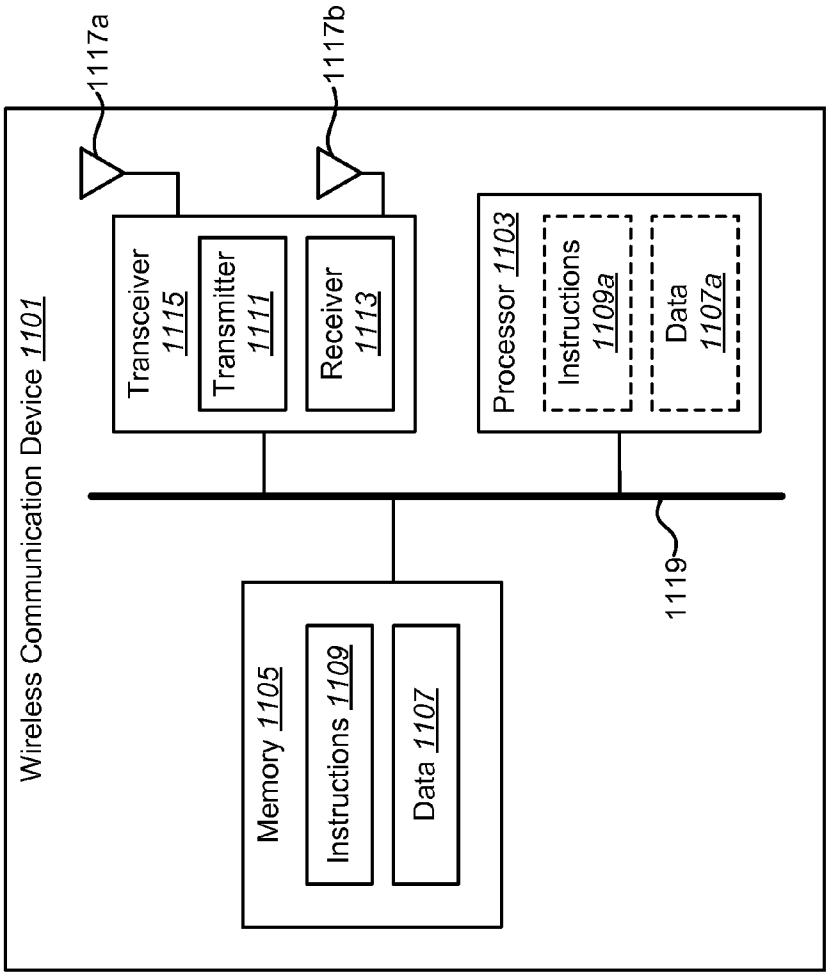

Wireless Communication Device 1101
1117a
1117b
Transceiver 1115
Transmitter 1111
Receiver 1113
Processor 1103
Instructions 1109a
Data 1107a
1119
Memory 1105
Instructions 1109
Data 1107

FIG. 11

INTERFERENCE REDUCTION USING VARIABLE DIGITAL-TO-ANALOG CONVERTER (DAC) SAMPLING RATES

RELATED APPLICATIONS

This application is related to and claims priority from U.S. Provisional Patent Application Ser. No. 61/220,965 filed Jun. 26, 2009, for "MULTIPLE BAND AND CONCURRENT TECHNOLOGY SUPPORT USING VARIABLE DIGITAL-TO-ANALOG CONVERTER (DAC) SAMPLING RATES."

TECHNICAL FIELD

The present disclosure relates generally to wireless communication systems. More specifically, the present disclosure relates to systems and methods for interference reduction using variable digital-to-analog converter (DAC) sampling rates.

BACKGROUND

Wireless devices have become smaller and more powerful in order to meet consumer needs and to improve portability and convenience. Consumers have become dependent upon wireless devices such as cellular telephones, personal digital assistants (PDAs), laptop computers and the like. Consumers have come to expect reliable service, expanded areas of coverage and increased functionality.

A wireless device may be capable of communicating using multiple wireless communication standards. A wireless device may be capable of communicating using a wireless local area network (WLAN), Bluetooth, cellular and Global Positioning System (GPS). In some instances, a wireless device may communicate using multiple wireless standards concurrently. For example, a Bluetooth stereo headset may receive music from a computer while the computer downloads songs from an Internet website using a wireless local area network (WLAN).

Transmissions sent by the wireless device may interfere with communications received by the wireless device or communications received by other wireless devices. For example, a digital-to-analog converter (DAC) may introduce DAC images into transmissions, which fall on or near the frequencies used by receivers for receiving. These DAC images may cause interference. Large and high powered filters can remove some of the DAC images, but at a high cost.

SUMMARY

A method for interference reduction is described. The method is implemented in a wireless device. A sampling frequency for a digital-to-analog converter (DAC) is selected so that images within a DAC output signal do not interfere with one or more receivers. A sample rate of an input signal that is provided to the DAC to match the sampling frequency for the DAC is adjusted.

A frequency or frequencies used by the one or more receivers may be determined. The sampling frequency for the DAC may be selected to avoid interference with the frequency or frequencies used by the one or more receivers. The sample rate of the input signal may be selected to avoid interference with the frequency or frequencies used by the one or more receivers. The input signal may be converted from a digital signal to an analog signal using the DAC with the selected sampling frequency.

The input signal may be split into an inphase digital signal and a quadrature digital signal. The inphase digital signal may be converted to an inphase analog signal using an inphase DAC (I-DAC) with the sampling frequency. The quadrature digital signal may be converted to a quadrature analog signal using a quadrature DAC (Q-DAC) with the sampling frequency.

The wireless device may be a multi-mode wireless communication device. The one or more receivers may include a cellular receiver, a Global Positioning System (GPS) receiver, a Bluetooth receiver or a Wireless Local Area Network (WLAN) receiver of the wireless device. The one or more receivers may also include a receiver on another wireless device.

One or more DAC images causing a failure of compliance testing for spurious emissions by the wireless device may be determined. The sampling frequency may be selected so that DAC images are not located in a restricted frequency band. The sample rate of the input signal may be adjusted using one or more interpolators. Outputs of the one or more interpolators may be input into a multiplexer. The one or more interpolators may be aligned serially. A final interpolator output may be input into a re-sampler. The sampling frequency for the DAC may be selected based on a band class in which a cellular transmitter of the wireless device is currently operating.

A multi-mode modem for a wireless device is also described. The multi-mode modem includes a controller that is configured to determine a sampling frequency for a digital-to-analog converter (DAC) so that images within the output signal of the DAC do not interfere with one or more receivers. The multi-mode modem also includes an interpolator bank that is configured to increase a sample rate of an input signal that is to be provided as an input to the DAC to match the determined sampling frequency for the DAC.

The multi-mode modem may also include a multiplexer that receives the output of each interpolator in the interpolator bank. The controller may be configured to select the output of an interpolator that is provided to the DAC. The multi-mode modem may further include a re-sampler that receives an input signal with a lower limit sample rate and provides an output signal with a sample rate between the lower limit sample rate and an upper limit sample rate. The controller may be configured to select the sample rate of the output signal.

The sampling frequency for the DAC may be selected to avoid interference with a frequency or frequencies used by the one or more receivers. The input signal may be split into an inphase digital signal and a quadrature digital signal. The multi-mode modem may include an inphase DAC (I-DAC) and a quadrature DAC (Q-DAC). The I-DAC may convert the inphase digital signal to an analog signal and the Q-DAC may convert the quadrature digital signal to an analog signal.

The one or more receivers may include a cellular receiver, a Global Positioning System (GPS) receiver, a Bluetooth receiver or a Wireless Local Area Network (WLAN) receiver of the wireless device. The one or more receivers may also include a receiver on another wireless device. The sampling frequency for the DAC may be determined so that DAC images are not located in a restricted frequency band. The multi-mode modem may also include a multiplexer. Outputs of the interpolator bank may be input into the multiplexer. The multi-mode modem may further include a re-sampler. The interpolator bank may include one or more interpolators aligned serially. A final interpolator output may be input into the re-sampler. The sampling frequency for the DAC may be

selected based on a band class in which a cellular transmitter of the wireless device is currently operating.

An apparatus for interference reduction is described. The apparatus includes means for selecting a sampling frequency for a digital-to-analog converter (DAC) so that images within a DAC output signal do not interfere with one or more receivers. The apparatus also includes means for adjusting a sample rate of an input signal that is provided to the DAC to match the sample frequency for the DAC.

A computer-program product comprising a computer-readable medium having instructions thereon is also described. The instructions include code for selecting a sampling frequency for a digital-to-analog converter (DAC) so that images within a DAC output signal do not interfere with one or more receivers. The instructions may also include code for adjusting a sample rate of an input signal that is provided to the DAC to match the sample frequency for the DAC.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a wireless communication system with multiple wireless devices;

FIG. **2** is a flow diagram of a method for adjusting sample rates in a digital-to-analog converter (DAC) to reduce interference;

FIG. **3** is a block diagram illustrating a zero intermediate frequency (IF) transmitter for use in the present systems and methods;

FIG. **4** is a flow diagram of a method for adjusting the digital-to-analog converter (DAC) sampling frequency to reduce interference;

FIG. **5** is a block diagram illustrating a sample rate adjuster for use in the present systems and methods;

FIG. **6** is a block diagram illustrating another sample rate adjuster for use in the present systems and methods;

FIG. **7** is a flow diagram of a method for adjusting the digital-to-analog converter (DAC) sampling frequency using interpolators;

FIG. **8** is a block diagram illustrating a configuration of the front-end architecture for a modem;

FIG. **9** is a graph illustrating the frequency response of a digital-to-analog converter (DAC) and an output of the digital-to-analog converter (DAC);

FIG. **10** illustrates certain components that may be included within a base station; and

FIG. **11** illustrates certain components that may be included within a wireless communication device.

DETAILED DESCRIPTION

FIG. **1** shows a wireless communication system **100** with multiple wireless devices **102**. A wireless device **102** may be a base station, a wireless communication device, a controller, or the like. A base station is a station that communicates with one or more wireless communication devices. A base station may also be referred to as, and may include some or all of the functionality of, an access point, a broadcast transmitter, a Node B, an evolved Node B, etc. The term "Base Station" will be used herein. Each base station provides communication coverage for a particular geographic area. A base station may provide communication coverage for one or more wireless communication devices. The term "cell" can refer to a base station and/or its coverage area, depending on the context in which the term is used.

A wireless communication device may also be referred to as, and may include some or all of the functionality of, a terminal, an access terminal, a user equipment (UE), a subscriber unit, a station, etc. A wireless communication device may be a cellular phone, a personal digital assistant (PDA), a wireless device, a wireless modem, a handheld device, a laptop computer, etc. A wireless communication device may communicate with zero, one or multiple base stations on the downlink and/or uplink at any given moment. The downlink (or forward link) refers to the communication link from a base station to a wireless communication device, and the uplink (or reverse link) refers to the communication link from a wireless communication device to a base station.

Wireless communication systems **100** may be multiple-access systems capable of supporting communication with multiple users by sharing the available system resources (e.g., bandwidth and transmit power). Examples of such multiple-access systems include code division multiple access (CDMA) systems, time division multiple access (TDMA) systems, frequency division multiple access (FDMA) systems, orthogonal frequency division multiple access (OFDMA) systems and spatial division multiple access (SDMA) systems.

A "multi-mode" wireless device **102** may use multiple wireless technologies simultaneously. Examples of such technologies include Bluetooth, cellular, wireless local area network (WLAN) and the Global Positioning System (GPS). In one configuration, the wireless device **102** may send cellular communications using a first antenna **104***a*, receive cellular communications using a second antenna **104***b* and receive other communications (e.g., Bluetooth, WLAN, GPS) using a third antenna **104***c*.

The wireless technologies may operate in different band classes. A band class is an allocation of a portion of the frequency spectrum for wireless communications. Examples of band classes include Cellular, Personal Communications Service (PCS) and International Mobile Telecommunications (IMT). Different frequencies may be utilized for different band classes. Different duplex offset may also be utilized for different band classes. The term "duplex offset" may refer to the difference in frequency between a wireless communications transmitter and a receiver. For example, the mobile transmit frequency is 824-849 MHz for the Cellular band class, 1850-1910 MHz for the PCS band class, 1920-1980 MHz for the IMT band class, etc. The duplex offset is 45 MHz (i.e., the receiver operates 45 MHz above the transmitter) for the cellular band class, 80 MHz for the PCS band class, 190 MHz for the IMT band class, etc.

A first wireless device **102***a* may use a primary transmitter **106** to transmit communications. In one configuration, the primary transmitter **106** may be a cellular transmitter. Transmitters are discussed in further detail below in relation to FIG. **3**. The primary transmitter **106** may prepare an input signal **108** for transmission via the first antenna **104***a*. For example, the primary transmitter **106** may convert the input signal **108** from a digital signal to an analog signal using a digital-to-analog converter (DAC) **120** prior to transmission.

The digital-to-analog converter (DAC) **120** may operate using a clock signal with a digital-to-analog converter (DAC) sampling frequency **118**. The digital-to-analog converter (DAC) **120** may produce an output signal having undesirable frequency "images." These images may result from the digital-to-analog converter (DAC) **120** output holding a particular value for one period of the clock cycle, so that the digital-to-analog converter (DAC) **120** output exactly matches the desired signal only once during each clock cycle. This is sometimes referred to as a zero-order hold. During the rest of the clock cycle, the digital-to-analog converter (DAC) **120** output and ideal signal may differ, creating error energy. Digital-to-analog converter (DAC) 120 images may be pro-

duced at harmonics of the digital-to-analog converter (DAC) sampling frequency **118**. For example, if the digital-to-analog converter (DAC) sampling frequency **118** is 100 megahertz (MHz), an undesirable image may be produced at 100 MHz, 200 MHz, 300 MHz, and so on.

The images produced by the digital-to-analog converter (DAC) **120** output signal may have implications for wireless devices **102**, particularly "multi-mode" devices that are configured to support multiple wireless technologies. For example, the wireless device **102***a* may include a primary receiver **122**. The primary receiver **122** may receive communications using the second antenna **104***b*. The received communications may be received at a primary receiver frequency **124**. If the images produced in the digital-to-analog converter (DAC) **120** output signal fall on or near the primary receiver frequency **124**, interference with the primary receiver **122** may occur. Likewise, if the images produced in the digital-to-analog converter (DAC) **120** output signal fall on or near a secondary receiver frequency **128** used by a secondary receiver **126** on the wireless device **102***a*, interference with the secondary receiver **126** may occur. A secondary receiver **126** on the wireless device **102***a* may receive wireless communications via a third antenna **104***c*. The secondary receiver **126** may receive Bluetooth signals, wireless local area network (WLAN) signals, Global Positioning System (GPS) signals, etc. A wireless device **102** may have multiple secondary receivers **126**, with each secondary receiver **126** having an antenna **104***c*.

The primary receiver frequency **124** may depend on the band class in which the primary transmitter **106** is currently operating. Thus, the digital-to-analog converter (DAC) sampling frequency **118** of the digital-to-analog converter (DAC) **120** may be adjusted based on the band class in which the primary transmitter **106** is currently operating. The primary receiver frequency **124** may also depend on which wireless technology is presently being used.

A second wireless device **102***b* may receive the transmitted signals from the first wireless device **102***a* using an antenna **104***d*. Interference may occur when the images produced in the digital-to-analog converter (DAC) **120** output signal fall on or near a receiver frequency **132** used by a receiver **130** on the second wireless device **102***b*.

Because a multi-mode wireless device **102** should be capable of operating in different band classes, it may be desirable that the digital-to-analog converter (DAC) sampling frequency **118** be selected so that DAC images do not cause interference with the primary receiver **122**, secondary receivers **126** or the receiver **130** on the second wireless device **102***b*. Specifically, the digital-to-analog converter (DAC) sampling frequency **118** may be chosen so that the multi-mode modem is able to work with all the possible band classes and duplex offsets that the multi-mode modem is supposed to be able to support. However, it may be extremely difficult to select a single digital-to-analog converter (DAC) sampling frequency **118** that will accomplish this objective. Instead, it may be beneficial for the digital-to-analog converter (DAC) sampling frequency **118** to be adjustable to avoid interference. The digital-to-analog converter (DAC) sampling frequency **118** may be adjusted so that images in the digital-to-analog converter (DAC) **120** output signal are outside of any frequency bands within which receivers of interest may be operating.

In order to adjust the digital-to-analog converter (DAC) sampling frequency **118**, the sample rate of the signal input to the digital-to-analog converter (DAC) **120** should also be changed. The primary receiver **106** may include a sample rate adjuster **110**. The sample rate adjuster **110** is discussed in additional detail below in relation to FIG. **3**. The sample rate adjuster **110** may receive an input signal **108**. The sample rate adjuster **110** may then adjust the sample rate for the input signal **108** and output a sample rate adjusted input signal **116** to a digital-to-analog converter (DAC) **120**. The sample rate adjuster **110** may also determine a digital-to-analog converter (DAC) sampling frequency **118**. The digital-to-analog converter (DAC) sampling frequency **118** may be output to the digital-to-analog converter (DAC) **120** by the sample rate adjuster **110**. By adjusting both the sample rate of the input signal **108** and the digital-to-analog converter (DAC) sampling frequency **118**, images in the digital-to-analog converter (DAC) **120** output may be moved in frequency to avoid interference.

FIG. **2** is a flow diagram of a method **200** for adjusting sample rates in a digital-to-analog converter (DAC) **120** to reduce interference. The method **200** may be performed by a wireless device **102***a*. The wireless device **102***a* may determine **202** a frequency or frequencies of one or more receivers. The one or more receivers may be receivers that can potentially receive interference from the wireless device **102***a*. The receivers may include a primary receiver **122** (such as a cellular receiver) on the wireless device **102***a*, a secondary receiver **126** (such as a Bluetooth receiver, a WLAN receiver or a GPS receiver) on the wireless device **102***a* and one or more receivers **130** on one or more other wireless devices **102***b*.

The wireless device **102***a* may select **204** a digital-to-analog converter (DAC) sampling frequency **118** to avoid interference with the determined frequency or frequencies. In one configuration, the digital-to-analog converter (DAC) sampling frequency **118** may depend on which wireless technology or technologies are being used by the wireless device **102***a*. The digital-to-analog converter (DAC) sampling frequency **118** may also depend on the wireless technologies being used by other nearby wireless devices **102***b*.

The wireless device **102***a* may also select **206** a signal sample rate for the input signal **108** to avoid interference with the determined frequency or frequencies. In order to adjust the sample rate of a digital-to-analog converter (DAC) **120**, both the digital-to-analog converter (DAC) sampling frequency **118** and the sample rate of the signal input into the digital-to-analog converter (DAC) **120** need to be changed. The wireless device **102***a* may then adjust **208** the sample rate of the input signal **108** using the selected signal sample rate to obtain a sample rate adjusted input signal **116**. The wireless device **102***b* may convert **210** the sample rate adjusted input signal **116** from a digital signal to an analog signal using a digital-to-analog converter (DAC) **120** with a digital-to-analog converter (DAC) sampling frequency **118**.

FIG. **3** is a block diagram illustrating a zero intermediate frequency (IF) transmitter **306** for use in the present systems and methods. The zero intermediate frequency (IF) transmitter **306** of FIG. **3** may be one configuration of the primary transmitter **106** of FIG. **1**. Although a zero intermediate frequency (IF) transmitter **306** is used for purposes of illustration, the techniques herein are not limited to zero intermediate frequency (IF) transmitters **306**. For example, a super heterodyne transmitter or a low intermediate frequency transmitter may also be used. In a zero intermediate frequency (IF) transmitter **306**, a signal may be directly upconverted from a baseband signal to a radio frequency (RF) signal without any intermediate frequency stages.

The zero intermediate frequency (IF) transmitter **306** may include a sample rate adjuster **310**. The sample rate adjuster **310** of FIG. **3** may be one configuration of the sample rate adjuster **110** of FIG. **1**. Sample rate adjusters **310** are dis-

cussed in further detail below in relation to FIG. **4** and FIG. **5**. The sample rate adjuster **310** may receive an input signal **308**. The input signal **308** may be a baseband signal. The sample rate adjuster **310** may include a signal sample rate **334**. The signal sample rate **334** may correspond to a determined digital-to-analog converter (DAC) sampling frequency **318**. In one configuration, the signal sample rate **334** and the digital-to-analog converter (DAC) sampling frequency **318** may be the same.

The sample rate adjuster **310** may output an inphase digital signal **336** and a quadrature digital signal **354**. The zero intermediate frequency (IF) transmitter **306** may include an inphase digital-to-analog converter (I-DAC) **338** and a quadrature digital-to-analog converter (Q-DAC) **356**. The inphase digital-to-analog converter (I-DAC) **338** may receive the inphase digital signal **336** and the digital-to-analog converter (DAC) sampling frequency **318** from the sample rate adjuster **310**. The inphase digital-to-analog converter (I-DAC) **338** may then convert the inphase digital signal **336** to an inphase analog signal **340** using the digital-to-analog converter (DAC) sampling frequency **318**. The inphase analog signal **340** may be filtered using an analog low pass filter (LPF) **342**. The quadrature digital-to-analog converter (Q-DAC) **356** may receive the quadrature digital signal **354** and the digital-to-analog converter (DAC) sampling frequency **318** from the sample rate adjuster **310**. The quadrature digital-to-analog converter (Q-DAC) **356** may then convert the quadrature digital signal **354** to a quadrature analog signal **358** using the digital-to-analog converter (DAC) sampling frequency **318**. The quadrature analog signal **358** may be filtered using an analog low pass filter (LPF) **360**.

Without adjusting the digital-to-analog converter (DAC) sampling frequency **318** of the quadrature digital-to-analog converter (Q-DAC) **356** and the inphase digital-to-analog converter (I-DAC) **338**, both the filtered quadrature analog signal **362** and the filtered inphase analog signal **344** may include undesirable frequency images introduced by the quadrature digital-to-analog converter (Q-DAC) **356** and the inphase digital-to-analog converter (I-DAC) **338** referred to as digital-to-analog converter (DAC) images. The low pass filters (LPFs) **342**, **360** typically do not attenuate the DAC images sufficiently to prevent the DAC images from interfering with receivers on the wireless device **102***a* and receivers on other wireless devices **102***b*. Instead of trying to filter out the DAC images, the DAC images may be moved in the frequency band so that they no long interfere with receivers on the wireless device **102***a* or receivers on other wireless devices **102***b*. Thus, the need for strong analog and/or RF filters to mitigate the interference caused by DAC images may be eliminated.

The filtered inphase analog signal **344** may be upconverted to a radio frequency (RF) using a first mixer **346** and a local oscillating signal **350** generated by a phase locked loop (PLL) **348**. The filtered quadrature analog signal **362** may be upconverted to a radio frequency (RF) using a second mixer **364** and the local oscillating signal **350** generated by the phase locked loop (PLL) **348**. Without adjusting the digital-to-analog converter (DAC) sampling frequency **318** of the quadrature digital-to-analog converter (Q-DAC) **356** and the inphase digital-to-analog converter (I-DAC) **338**, both the upconverted quadrature analog signal **352** and the upconverted quadrature analog signal **366** may include undesirable frequency images that have also been upconverted to radio frequency (RF). These upconverted DAC images may interfere with the primary receiver **122**, secondary receivers **126** and receivers **130** located outside of the wireless device **102***a*, making it more difficult for these receivers to demodulate and receive their respective signals.

By adjusting the digital-to-analog converter (DAC) sampling frequency **318**, the upconverted inphase analog signal **352** and the upconverted quadrature analog signal **366** may have adjusted DAC images, decreasing the likelihood of interference. The upconverted inphase analog signal **352** and the upconverted quadrature analog signal **366** may then be added using an adder **368** to obtain a combined signal **370**. The combined signal **370** may be amplified using an Automatic Gain Control (AGC) amplifier **372** and then transmitted using an antenna **304***a*.

FIG. **4** is a flow diagram of a method **400** for adjusting the digital-to-analog converter (DAC) sampling frequency **318** to reduce interference. The method **400** may be performed by a wireless device **102***a*. The method **400** may be implemented in software, firmware or hardware of the wireless device **102***a* (e.g., in a multi-mode modem that is included within a wireless device **102***a*).

The wireless device **102***a* may determine **402** the frequency or frequencies of one or more receivers on the wireless device **102***a*. The frequency of a receiver may refer to the frequency at which the receiver receives desired signals. The wireless device **102***a* may select **404** a digital-to-analog converter (DAC) sampling frequency **318** to avoid interference with the determined frequency or frequencies. For example, the wireless device **102***a* may select a digital-to-analog converter (DAC) sampling frequency **318** such that DAC images, when upconverted to radio frequency (RF), do not interfere with the determined frequency or frequencies. In one configuration, the digital-to-analog converter (DAC) sampling frequency **318** may be selected so that frequencies of upconverted DAC images differ from the determined frequency or frequencies by at least 2 MHz.

The wireless device **102***a* may select **406** a signal sample rate **334** for an input signal **308** to avoid interference with the determined frequency or frequencies. The signal sample rate **334** and the digital-to-analog converter (DAC) clock rate (i.e., the digital-to-analog converter (DAC) sampling frequency **118**) are the same. The wireless device **102***a* may adjust **408** the sample rate **334** of the input signal **308** to the selected signal sample rate **344** to obtain a sample rate adjusted input signal **116**. The sample rate adjusted input signal **116** may thus be the input signal **308** with an adjusted sample rate.

The wireless device **102***a* may split **410** the sample rate adjusted input signal **116** into an inphase digital signal **336** and a quadrature digital signal **354**. The wireless device **102***a* may then convert **412** the inphase digital signal **336** to an inphase analog signal **340** using an inphase digital-to-analog converter (I-DAC) **338** with the digital-to-analog converter (DAC) sampling frequency **318**. The wireless device **102***a* may also convert **414** the quadrature digital signal **354** to a quadrature analog signal **358** using a quadrature digital-to-analog converter (Q-DAC) **356**.

FIG. **5** is a block diagram illustrating a sample rate adjuster **510** for use in the present systems and methods. The sample rate adjuster **510** of FIG. **5** may be one configuration of the sample rate adjuster **110** of FIG. **1**. The sample rate adjuster **510** may receive an input signal **508***a*. The input signal **508***a* may be provided to one or more interpolators **574***a-n*. Each successive interpolator **574** may double the sample rate for the input signal **508***a*. For example, in a CDMA system, the chip rate (cx) of the input signal **508***a* may be cx1, the chip rate of the output **508***b* of the first interpolator **574***a* may be cx2 (twice the chip rate of the input signal) and the chip rate

of the output **508***c* of the second interpolator **574***b* may be cx4. A group of interpolators **574** may be referred to as an interpolator bank.

A CDMA2000 system may have a fundamental chip rate of 1.2288 MHz. The fundamental chip rate may be referred to as chipx1. Using interpolators **574**, the chip rate may be increased to chipx2 (i.e., 1.2288 MHz×2), chipx4 (i.e., 1.2288 MHz×4), chipx8, chipxl6, chipx32, chipx64, etc.

In one configuration, the output **508***b-n* of an interpolator **574** may be any integer multiple of the sample rate of the input signal **508***a*. An interpolator **574** may be configured to insert a certain number of zeroes between adjacent samples. An interpolator **574** may also include an anti-aliasing filter.

The output of each interpolator **574** may be provided as an input to a multiplexer **576**. A control signal **580** may be provided as an input to the multiplexer **576**, allowing selection of which output is passed as the inphase digital signal **536** and the quadrature digital signal **554**. The inphase digital signal **536** and the quadrature digital signal **554** together represent the complex modulation of the transmit signal. Since the transmit signal has both amplitude and phase modulation, it is by definition complex and requires both an inphase component and a quadrature component.

The control signal **580** may be generated by a controller **578** that determines what the sample rates of the inphase digital signal **536** and the quadrature digital signal **554** should be to avoid interference. The controller **578** may also select the digital-to-analog converter (DAC) sampling frequency **518** of the inphase digital-to-analog converter (I-DAC) **338** and the quadrature digital-to-analog converter (Q-DAC) **356** to avoid interference. Typically, the digital-to-analog converter (DAC) sampling frequency **518** comes from a phase locked loop (PLL) and digital dividers.

FIG. **6** is a block diagram illustrating another sample rate adjuster **610** for use in the present systems and methods. The sample rate adjuster **610** of FIG. **6** may be one configuration of the sample rate adjuster **110** of FIG. **1**. The sample rate adjuster **610** may receive an input signal **608**. The input signal **608** may then be provided to a first interpolator **674***a*. The output of the first interpolator **674***a* may be input into a second interpolator **674***b*. The input signal **608** may be provided to additional interpolators **674**. The output of a final interpolator **674***n* may then be provided to a re-sampler **682**. The re-sampler **682** may be a special kind of interpolator. Unlike an interpolator **674**, the sample rate of the output of the re-sampler **682** does not have to be an integer multiple of the sample rate of the input signal **608**.

For example, the re-sampler **682** may be configured to accept an input at a particular lower limit sample rate (e.g., cx64) and provide an output at any rate between the lower limit sample rate and a particular upper limit sample rate (e.g., cx128). Thus, the use of a re-sampler **682** makes it possible for the DAC images to be placed in any desired frequency location within a given range (which depends on the lower limit sample rate and the upper limit sample rate). A controller **678** may instruct the re-sampler **682** concerning the specific sample rate that the input signal **608** should be sampled at using a control signal **680**. Multiple interpolators **674***a-n* may be used to change the sample rate of the input signal **608** to the desired lower limit sampling rate prior to passing the input signal **608** through the re-sampler **682**.

The re-sampler **682** may output an inphase digital signal **636** and a quadrature digital signal **654**. Both the inphase digital signal **636** and the quadrature digital signal **654** may have the desired sampling rate. The re-sampler **682** may also output a digital-to-analog converter (DAC) sampling frequency **618**. The digital-to-analog converter (DAC) sampling frequency **618** may be the same as the sample rate of the inphase digital signal **636** and the quadrature digital signal **654**.

In one configuration, the sample rate adjuster **110** of FIG. **1** may include a combination of the sample rate adjuster **510** of FIG. **5** and the sample rate adjuster **610** of FIG. **6**.

FIG. **7** is a flow diagram of a method **700** for adjusting the digital-to-analog converter (DAC) sampling frequency **318** using interpolators **574**, **674**. The method **700** may be performed by a wireless device **102***a*. The wireless device **102***a* may determine **702** digital-to-analog converter (DAC) images causing a failure of compliance testing for spurious emissions. The term "spurious emissions" may refer to any radio frequency not deliberately created or transmitted. Spurious emissions are often generated by a device that does not create other frequencies. A harmonic or other signal outside a transmitter's assigned channel is typically considered a spurious emission. The DAC images falling within a restricted frequency band may be spurious emissions. Depending on the strength of the digital-to-analog converter (DAC) emissions, the wireless device **102***a* may fail compliance testing requirements.

There are various spurious emissions requirements that a wireless device **102***a* may have to comply with. For example, a government agency may specify that for transmissions in a particular frequency band, any output in an adjacent frequency band (such as a restricted frequency band) has to fall below a certain threshold.

The wireless device **102***a* may select **704** a digital-to-analog converter (DAC) sampling frequency **318** so that the DAC images are not located in a restricted frequency band. The wireless device **102***a* may also select **706** a signal sample rate **334** for an input signal **308** so that the DAC images are not located in a restricted frequency band. In one configuration, the signal sample rate **334** and the digital-to-analog converter (DAC) sampling frequency **318** may be the same.

The wireless device may adjust **708** the sample rate of the input signal **308** to the signal sample rate **334** using one or more interpolators **574**, **674**. The wireless device **102***a* may adjust the sample rate of the input signal **308** using a multiplexer **576** as illustrated in FIG. **5** or a re-sampler **682** as illustrated in FIG. **6**. The wireless device **102***a* may also adjust **710** the digital-to-analog converter (DAC) sampling frequency **318** using one or more interpolators **574**, **674**. The wireless device **102***a* may then convert **712** the input signal **308** from a digital signal to an analog signal using the digital-to-analog converter (DAC) **120**.

FIG. **8** is a block diagram illustrating a configuration of the front-end architecture for a modem **884**. The modem **884** may be part of a wireless device **102***a*. A transmission signal stream may be sent through a modulator **885** to prepare the signal stream for conveying a message. An inverse fast Fourier transform (IFFT) **886** may convert the signal stream from the frequency domain to the time domain. A baseband (BB) filter **887** may filter out the undesired high frequency images. A digital-to-analog converter (DAC) **820** may convert the digital signal stream to an analog signal stream and an analog filter **889** may provide additional filtering to the signal stream to further reduce the higher frequency images.

A mixer **890** may convert the analog baseband signal to RF frequencies. A variable gain amplifier (VGA) **891** may maintain a desired output signal level by controlling the gain of the signal stream. Finally, the signal stream may be passed through a Bulk Acoustic Wave (BAW) filter **892** before being transmitted by an antenna **804***a*. The Bulk Acoustic Wave (BAW) filter **892** is an RF passband filter at the center frequency of the transmit channel with a stopband that further

suppresses the high frequency images, so that the images are well below the noise floor of the receiver for the receive channel.

FIG. **9** is a graph illustrating the frequency response **994** of a digital-to-analog converter (DAC) **120** and an output **996** of the digital-to-analog converter (DAC) **120**. The amplitude of the frequency response **994** may roll off with increasing frequency according to a sinc function

$$\left(\text{i.e., } \frac{\sin(\pi x)}{\pi x}\right),$$

leaving "nulls" of very weak image energy around the integer multiples of the sample rate.

The output **996** of the digital-to-analog converter (DAC) **120** may include DAC images **998** around the "nulls" of the frequency response **994**. These DAC images **998** interfere with the primary receiver **122** on the wireless device **102***a*, a secondary receiver **126** on the wireless device **102***a* or a receiver **130** on another wireless device **102***b*.

FIG. **10** illustrates certain components that may be included within a base station **1001**. The base station **1001** may be an access point, a NodeB, an evolved NodeB, etc. The base station **1001** includes a processor **1003**. The processor **1003** may be a general purpose single- or multi-chip microprocessor (e.g., an ARM), a special purpose microprocessor (e.g., a digital signal processor (DSP)), a microcontroller, a programmable gate array, etc. The processor **1003** may be referred to as a central processing unit (CPU). Although just a single processor **1003** is shown in the base station **1001** of FIG. **10**, in an alternative configuration, a combination of processors (e.g., an ARM and DSP) could be used.

The base station **1001** also includes memory **1005**. The memory **1005** may be any electronic component capable of storing electronic information. The memory **1005** may be embodied as random access memory (RAM), read-only memory (ROM), magnetic disk storage media, optical storage media, flash memory devices in RAM, on-board memory included with the processor, EPROM memory, EEPROM memory, registers, and so forth, including combinations thereof.

Data **1007** and instructions **1009** may be stored in the memory **1005**. The instructions **1009** may be executable by the processor **1003** to implement the methods disclosed herein. Executing the instructions **1009** may involve the use of the data **1007** that is stored in the memory **1005**. When the processor **1003** executes the instructions **1009**, various portions of the instructions **1009***a* may be loaded onto the processor **1003**, and various pieces of data **1007***a* may be loaded onto the processor **1003**.

The base station **1001** may also include a transmitter **1011** and a receiver **1013** to allow transmission and reception of signals to and from the wireless device **1001**. The transmitter **1011** and receiver **1013** may be collectively referred to as a transceiver **1015**. Multiple antennas **1017***a-b* may be electrically coupled to the transceiver **1015**. The base station **1001** may also include (not shown) multiple transmitters, multiple receivers and/or multiple transceivers.

The various components of the base station **1001** may be coupled together by one or more buses, which may include a power bus, a control signal bus, a status signal bus, a data bus, etc. For the sake of clarity, the various buses are illustrated in FIG. **10** as a bus system **1019**.

FIG. **11** illustrates certain components that may be included within a wireless communication device **1101**. The wireless communication device **1101** may be an access terminal, a mobile station, a user equipment (UE), etc. The wireless communication device **1101** includes a processor **1103**. The processor **1103** may be a general purpose single- or multi-chip microprocessor (e.g., an ARM), a special purpose microprocessor (e.g., a digital signal processor (DSP)), a microcontroller, a programmable gate array, etc. The processor **1103** may be referred to as a central processing unit (CPU). Although just a single processor **1103** is shown in the wireless communication device **1101** of FIG. **11**, in an alternative configuration, a combination of processors (e.g., an ARM and DSP) could be used.

The wireless communication device **1101** also includes memory **1105**. The memory **1105** may be any electronic component capable of storing electronic information. The memory **1105** may be embodied as random access memory (RAM), read-only memory (ROM), magnetic disk storage media, optical storage media, flash memory devices in RAM, on-board memory included with the processor, EPROM memory, EEPROM memory, registers, and so forth, including combinations thereof.

Data **1107** and instructions **1109** may be stored in the memory **1105**. The instructions **1109** may be executable by the processor **1103** to implement the methods disclosed herein. Executing the instructions **1109** may involve the use of the data **1107** that is stored in the memory **1105**. When the processor **1103** executes the instructions **1109**, various portions of the instructions **1109***a* may be loaded onto the processor **1103**, and various pieces of data **1107***a* may be loaded onto the processor **1103**.

The wireless communication device **1101** may also include a transmitter **1111** and a receiver **1113** to allow transmission and reception of signals to and from the wireless communication device **1101**. The transmitter **1111** and receiver **1113** may be collectively referred to as a transceiver **1115**. Multiple antennas **1117***a-b* may be electrically coupled to the transceiver **1115**. The wireless communication device **1101** may also include (not shown) multiple transmitters, multiple receivers and/or multiple transceivers.

The various components of the wireless communication device **1101** may be coupled together by one or more buses, which may include a power bus, a control signal bus, a status signal bus, a data bus, etc. For the sake of clarity, the various buses are illustrated in FIG. **11** as a bus system **1119**.

The term "determining" encompasses a wide variety of actions and, therefore, "determining" can include calculating, computing, processing, deriving, investigating, looking up (e.g., looking up in a table, a database or another data structure), ascertaining and the like. Also, "determining" can include receiving (e.g., receiving information), accessing (e.g., accessing data in a memory) and the like. Also, "determining" can include resolving, selecting, choosing, establishing and the like.

The phrase "based on" does not mean "based only on," unless expressly specified otherwise. In other words, the phrase "based on" describes both "based only on" and "based at least on."

The term "processor" should be interpreted broadly to encompass a general purpose processor, a central processing unit (CPU), a microprocessor, a digital signal processor (DSP), a controller, a microcontroller, a state machine, and so forth. Under some circumstances, a "processor" may refer to an application specific integrated circuit (ASIC), a programmable logic device (PLD), a field programmable gate array (FPGA), etc. The term "processor" may refer to a combination of processing devices, e.g., a combination of a DSP and

a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

The term "memory" should be interpreted broadly to encompass any electronic component capable of storing electronic information. The term memory may refer to various types of processor-readable media such as random access memory (RAM), read-only memory (ROM), non-volatile random access memory (NVRAM), programmable read-only memory (PROM), erasable programmable read-only memory (EPROM), electrically erasable PROM (EEPROM), flash memory, magnetic or optical data storage, registers, etc. Memory is said to be in electronic communication with a processor if the processor can read information from and/or write information to the memory. Memory that is integral to a processor is in electronic communication with the processor.

The terms "instructions" and "code" should be interpreted broadly to include any type of computer-readable statement (s). For example, the terms "instructions" and "code" may refer to one or more programs, routines, sub-routines, functions, procedures, etc. "Instructions" and "code" may comprise a single computer-readable statement or many computer-readable statements.

The functions described herein may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored as one or more instructions on a computer-readable medium. The terms "computer-readable medium" or "computer-program product" refers to any available medium that can be accessed by a computer. By way of example, and not limitation, a computer-readable medium may comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code in the form of instructions or data structures and that can be accessed by a computer. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and Blu-ray® disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers.

Software or instructions may also be transmitted over a transmission medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of transmission medium.

The methods disclosed herein comprise one or more steps or actions for achieving the described method. The method steps and/or actions may be interchanged with one another without departing from the scope of the claims. In other words, unless a specific order of steps or actions is required for proper operation of the method that is being described, the order and/or use of specific steps and/or actions may be modified without departing from the scope of the claims.

Further, it should be appreciated that modules and/or other appropriate means for performing the methods and techniques described herein, such as those illustrated by FIGS. **2**, **4** and **7**, can be downloaded and/or otherwise obtained by a device. For example, a device may be coupled to a server to facilitate the transfer of means for performing the methods described herein. Alternatively, various methods described herein can be provided via a storage means (e.g., random access memory (RAM), read-only memory (ROM), a physical storage medium such as a compact disc (CD) or floppy disk, etc.), such that a device may obtain the various methods upon coupling or providing the storage means to the device. Moreover, any other suitable technique for providing the methods and techniques described herein to a device can be utilized.

It is to be understood that the claims are not limited to the precise configuration and components illustrated above. Various modifications, changes and variations may be made in the arrangement, operation and details of the systems, methods, and apparatus described herein without departing from the scope of the claims.

What is claimed is:

1. A method for interference reduction, the method being implemented in a wireless device, the method comprising:

selecting a sampling frequency for a digital-to-analog converter (DAC) so that images within a DAC output signal do not interfere with one or more receivers, wherein the DAC has an adjustable sampling frequency so as to be operable at a plurality of sampling frequencies; and

adjusting a sample rate of an input signal that is provided to the DAC to match the selected sampling frequency for the DAC.

2. The method of claim **1**, further comprising:

determining a frequency or frequencies used by the one or more receivers, wherein the selected sampling frequency for the DAC is selected to avoid interference with the frequency or frequencies used by the one or more receivers; and

selecting the sample rate of the input signal to avoid interference with the frequency or frequencies used by the one or more receivers.

3. The method of claim **1**, further comprising converting the input signal from a digital signal to an analog signal using the DAC with the selected sampling frequency.

4. The method of claim **1**, further comprising splitting the input signal into an inphase digital signal and a quadrature digital signal.

5. The method of claim **4**, further comprising:

converting the inphase digital signal to an inphase analog signal using an inphase DAC (I-DAC) with the selected sampling frequency; and

converting the quadrature digital signal to a quadrature analog signal using a quadrature DAC (Q-DAC) with the selected sampling frequency.

6. The method of claim **1**, wherein the wireless device is a multi-mode wireless communication device.

7. The method of claim **1**, wherein the one or more receivers comprises a cellular receiver of the wireless device.

8. The method of claim **1**, wherein the one or more receivers comprises a Global Positioning System (GPS) receiver of the wireless device.

9. The method of claim **1**, wherein the one or more receivers comprises a Bluetooth receiver of the wireless device.

10. The method of claim **1**, wherein the one or more receivers comprises a Wireless Local Area Network (WLAN) receiver of the wireless device.

11. The method of claim **1**, wherein the one or more receivers comprises a receiver on another wireless device.

12. The method of claim **11**, further comprising determining one or more DAC images causing a failure of compliance testing for spurious emissions by the wireless device, wherein the selected sampling frequency is selected so that DAC images are not located in a restricted frequency band.

13. The method of claim **1**, wherein a sample rate of the input signal is adjusted using one or more interpolators.

14. The method of claim **13**, wherein outputs of the one or more interpolators are input into a multiplexer.

15. The method of claim 13, wherein the one or more interpolators are aligned serially, and wherein a final interpolator output is input into a re-sampler.

16. The method of claim 1, wherein the selected sampling frequency for the DAC is selected based on a band class in which a cellular transmitter of the wireless device is currently operating.

17. A multi-mode modem for a wireless device, comprising:

a controller that is configured to determine a sampling frequency for a digital-to-analog converter (DAC) so that images within the output signal of the DAC do not interfere with one or more receivers, wherein the DAC has an adjustable sampling frequency so as to be operable at a plurality of sampling frequencies; and

an interpolator bank that is configured to increase a sample rate of an input signal that is to be provided as an input to the DAC to match the determined sampling frequency for the DAC.

18. The multi-mode modem of claim 17, further comprising a multiplexer, wherein the multiplexer receives the output of each interpolator in the interpolator bank, and wherein the controller is configured to select the output of an interpolator that is provided to the DAC.

19. The multi-mode modem of claim 17, further comprising a re-sampler, wherein the re-sampler receives an input signal with a lower limit sample rate and provides an output signal with a sample rate between the lower limit sample rate and an upper limit sample rate, and wherein the controller is configured to select the sample rate of the output signal.

20. The multi-mode modem of claim 17, wherein the determined sampling frequency for the DAC is determined to avoid interference with a frequency or frequencies used by the one or more receivers.

21. The multi-mode modem of claim 17, wherein the input signal is split into an inphase digital signal and a quadrature digital signal.

22. The multi-mode modem of claim 21, further comprising an inphase DAC (I-DAC) and a quadrature DAC (Q-DAC), wherein the I-DAC converts the inphase digital signal to an analog signal and the Q-DAC converts the quadrature digital signal to an analog signal.

23. The multi-mode modem of claim 17, wherein the one or more receivers comprises a cellular receiver of the wireless device.

24. The multi-mode modem of claim 17, wherein the one or more receivers comprises a Global Positioning System (GPS) receiver of the wireless device.

25. The multi-mode modem of claim 17, wherein the one or more receivers comprises a Bluetooth receiver of the wireless device.

26. The multi-mode modem of claim 17, wherein the one or more receivers comprises a Wireless Local Area Network (WLAN) receiver of the wireless device.

27. The multi-mode modem of claim 17, wherein the one or more receivers comprises a receiver on another wireless device.

28. The multi-mode modem of claim 27, wherein the determined sampling frequency for the DAC is determined so that DAC images are not located in a restricted frequency band.

29. The multi-mode modem of claim 17, further comprising a multiplexer, wherein outputs of the interpolator bank are input into the multiplexer.

30. The multi-mode modem of claim 17, further comprising a re-sampler, wherein the interpolator bank comprises one or more interpolators aligned serially, and wherein a final interpolator output is input into the re-sampler.

31. The multi-mode modem of claim 17, wherein the determined sampling frequency for the DAC is determined based on a band class in which a cellular transmitter of the wireless device is currently operating.

32. An apparatus for interference reduction, comprising:

means for selecting a sampling frequency for a digital-to-analog converter (DAC) so that images within a DAC output signal do not interfere with one or more receivers, wherein the DAC has an adjustable sampling frequency so as to be operable at a plurality of sampling frequencies; and

means for adjusting a sample rate of an input signal that is provided to the DAC to match the selected sample frequency for the DAC.

33. A computer-program product comprising a non-transitory computer-readable medium having instructions thereon, the instructions comprising:

code for selecting a sampling frequency for a digital-to-analog converter (DAC) so that images within a DAC output signal do not interfere with one or more receivers, wherein the DAC has an adjustable sampling frequency so as to be operable at a plurality of sampling frequencies; and

code for adjusting a sample rate of an input signal that is provided to the DAC to match the selected sample frequency for the DAC.

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